Enhancing Small Millet Farming Resilience Through Conservation Agriculture in Rainfed Regions

Abstract

The Centre of Excellence in Millets, located in Athiyandal, Tamil Nadu, conducted an extensive study from kharif 2020 to 2022, focusing on the impact of conservation agriculture practices on small millet crops in rainfed areas. The experiment, designed in a split-plot layout, included three main plot treatments: No tillage, Minimal tillage, and Mulching, with six sub-plot treatments comprising various millet varieties. Results indicated that a single ploughing significantly reduced weed populations, while mulching played a crucial role in curbing weed growth and conserving water. This led to substantial increases in grain yield and straw yield, ranging from 24.3% to 36.1% over the control, alongside an improvement in relative water use efficiency (RWUE) from 5.16 to 7.03 kg/ha/mm. Among the various millets cultivated with the mulching treatment (S3) emerged as the most favorable option in terms of grain yield. Finger millet, Kodomillet, and Foxtail millet exhibited the highest yields under this treatment, with 3010 kg/ha, 2234 kg/ha, and 2003 kg/ha, respectively. Additionally, Little millet, Barnyard millet, and Proso millet also demonstrated improved yields under Mulching, recording 1015 kg/ha, 1004 kg/ha, and 910 kg/ha, respectively. These results conclude that small millet cultivation in rainfed areas with mulching practices effectively enhances grain production, reduces weed growth, and ensures optimal water conservation, thereby providing sustainable alternatives to herbicide usage.

Key words : Zero tillage, Mulching, Rainwater use efficiency

1. INTRODUCTION

In contemporary agriculture, farmers face a complex landscape characterized by various challenges and opportunities. Climate change, soil degradation, water scarcity, and diminishing biodiversity pose significant threats to agricultural productivity and sustainability. Additionally, farmers grapple with fluctuating market prices, rising input costs, and the need to meet increasing food demands from a growing global population. In this context, conservation agriculture emerges as a compelling solution to address these multifaceted challenges at both the farm and societal levels.

Conservation agriculture marks a significant departure from conventional farming practices, emphasizing sustainable methodologies (FAO, 2022) (7) that not only bolster crop yields but also prioritize the long-term health of the land (Page *et al*., 2020) (17). This holistic approach integrates three core principles: minimal soil disturbance, permanent soil cover, and diversified crop rotations. By adhering to these principles, farmers can mitigate the environmental impact of agriculture while fostering resilience and productivity (Somasundaram *et al*., 2021) (19). Traditional farming often entails intensive tillage, disrupting the soil's natural structure and resulting in soil erosion, loss of organic matter, and increased vulnerability to pests and diseases. Conservation agriculture advocates for reduced or no-till farming, preserving the soil's integrity (Cameron *et al*., 2015) (3). By minimizing disturbance, farmers can prevent erosion, enhance water retention, and maintain a healthier soil ecosystem (Kassam *et al*., 2019; Dalal *et* *al*., 2011) (12). Another cornerstone of conservation agriculture is maintaining permanent soil cover, achieved through strategic use of cover crops or crop residues (Happs*et al*., 2008; Abrol *et al*., 2005) (8,1). Cover crops, sown during non-growing seasons, shield the soil from erosion and contribute organic matter. Leaving crop residues on the field post-harvest further shields the soil, suppressing weed growth, and enhancing fertility (Kaschuk*et al*., 2010; Kirkegaard, 1995; Duan *et al*., 2010) (11,13,6). This practice not only conserves soil but also promotes water retention and reduces the need for external inputs. Conservation agriculture acknowledges the significance of diversified crop rotations in fostering resilient and sustainable farming systems. Crop rotation disrupts pest and disease cycles, enhances soil health, and optimizes nutrient balance (Nhamo and Lungu, 2017) (16). This diversity not only benefits the environment but also diminishes reliance on chemical inputs (Silban*et al*., 2020) (18), contributing to a more environmentally friendly and economically viable agricultural model.

Small millet cultivation in rainfed areas confronts multifaceted challenges, including water scarcity, weed competition, soil erosion, and limited input availability. Erratic rainfall patterns and prolonged droughts intensify water shortages, while persistent weed infestation undermines crop productivity. Soil erosion further exacerbates these issues, particularly in sloping terrains, worsened by scarce access to essential agricultural inputs like fertilizers and high-quality seeds. In response, the current study seeks to identify and implement effective conservation practices tailored to small millet farming in rainfed regions.

2. MATERIALS AND METHODS

The field experiment took place at the Centre of Excellence in Millets, Athiyandal,Tamil Nadu covering the *Kharif* seasons from 2020 to 2022. Initial Soil analysis revealed low levels of available nitrogen (137.0 kg/ha), high levels of available phosphorus (32.1 kg/ha), and medium levels of potassium (141.0 kg/ha) (Table 1.). The study involved three treatments in main plots *viz*., S_1 – No tillage; S_2 – Minimal tillage, and S_3 - Mulching and six treatments in the sub plot: Six small millet crops, namely C_1 - Finger Millet, C_2 - Kodo Millet, C_3 - Foxtail Millet, C_4 - Little Millet, C_5 - Barnyard Millet, and C_6 - Proso Millet, and. A split plot design was employed, with each treatment replicated three times. Crop planting maintained a spacing of 30 cm × 10 cm, utilizing the ATL 1 variety for all small millet crops (Foxtail millet, Finger millet, Little millet, Proso millet, and Kodo millet, except for Barnyard millet Co(KV)2). Fertilizer application followed All Indiarecommended doses, with 40 kg/ha of urea, 20 kg/ha of superphosphate, and 20 kg/ha of muriate of potash applied as a basal dose, along with appropriate top dressing. Adherence to all recommended agricultural practices ensured the crop's specific requirements were met throughout the experiment.The treatments were implemented prior to crop cultivation. Under no tillage conditions, sowing commenced after rainfall, while minimal tillage involved only one tillage event before sowing. In the mulching treatment, previous crop residues were spread. The average rainfall pattern during the cropping period is depicted in Fig. 1. Upon completion, the collected data will undergo statistical analysis following Gomez and Gomez (1984) guidelines. This analysis aims to discern thetreatments' influence on the growth and yield attributes of small millets. Significant differences will be determined at a five percent (0.05) probability level to interpret the results.

Table 1. Initial soil parameters

Details	Value
I. Physical properties	
Texture	Sandy clay loam
II. Chemical properties	
1. pH	7.2
2. EC ds m^{-1}	0.20
3. Organic carbon %	0.48
4. Available N kg/ ha^{-1}	137.0
5. Available P kg/ ha^{-1}	32.1
6. Available K kg/ ha^{-1}	141.0

Treatments

Zero tillage / Minimum tillage: Millet fields may experience advantageous outcomes through the adoption of reduced or zero tillage techniques. Instead of employing extensive plowing methods, minimal tillage strategies focus on loosening the soil solely within the planting rows or utilizing specialized tools such as chisel plows or disc harrows. By implementing this approach, soil moisture conservation is promoted, erosion is mitigated, and soil structure is preserved, all while reducing the overall disruption to the soil ecosystem.

Mulching : Spreading crop residues, such as the straws from prior millet crops, within the field post-harvest can yield significant benefits. These mulching materials serve as a protective layer on the soil surface, diminishing evaporation, enhancing water infiltration, inhibiting weed proliferation, moderating soil temperature, and mitigating soil erosion. Additionally, these residues play a pivotal role in enriching organic matter content and facilitating nutrient recycling within the soil.

3. RESULT AND DISCUSSION

3.1. Plant height

Plant height is crucial for light absorption, impacting photosynthesis and overall growth. In agriculture, it directly correlates with crop yield and influences harvesting methods. Additionally, plant height plays a role in ecological interactions, affecting relationships with pollinators, herbivores, and the plant's adaptation to its environment. The plant heights of diverse millet crops, observed under distinct treatments, reveal unique growth trends. In the comparison across all three treatments, it is evident that Treatment S_3 - Mulching consistently yielded higher plant heights compared to other treatments. Specifically, the plant heights were recorded as 95.7 cm, 77.1 cm, 94.3 cm, 93.4 cm, 114.1 cm, and 114.2 cm for Finger Millet, Kodo Millet, Foxtail Millet, Little Millet, Barnyard Millet, and Proso Millet, respectively, under mulching treatment (Table 2.).

3.2. Number of tillers

Tillers is a key factor influencing crop yield, as they often develop into productive stems or ears. Efficient tillering is crucial for optimizing plant growth and achieving higher agricultural productivity. The tiller characteristics of various millet crops under different treatments exhibit distinct patterns. Upon comparing all three treatments, Treatment S_3 - Mulchingconsistently resulted in a higher number of tillers compared to Treatments S_1 and S_2. Specifically, the tiller counts were recorded as 4, 12, 4, 4, 4, and 5 for Finger Millet, Kodo Millet, Foxtail Millet, Little Millet, Barnyard Millet, and Proso Millet, respectively, under Treatment S_3(Table 2.).

3.3. 1000 grain weight

The 1000 grain weight, a crucial metric reflecting the average weight of a thousand grains, demonstrates distinctive trends among different millet crops under various treatments. Upon careful examination of all three treatments, it is apparent that Treatment S_3 - Mulching consistently yields higher 1000 grain weights compared to S_1- No tillage and S_2 – Minimal tillage. Specifically, the 1000 grain weights were recorded as 2.9, 3.9, 3.19, 3.69, 3.98, and 5.08 for Finger Millet, Kodo Millet, Foxtail Millet, Little Millet, Barnyard Millet, and Proso Millet, respectively, under S_3 - Mulching(Table 2.).

3.4. Grain yield

The grain yield, a pivotal measure indicating the amount of harvested grains per unit area, reveals distinctive patterns across various millet crops and treatments. Upon thorough examination of all three treatments, it is evident that Treatment S_3 - Mulching consistently results in higher grain yields compared to S_1- No tillage and S_2 – Minimal tillage. Specifically, the grain yields were recorded as 3010 kg/ha for Finger Millet, 2234 kg/ha for Kodo Millet, 2003 kg/ha for Foxtail Millet, 1015 kg/ha for Little Millet, 1004 kg/ha for Barnyard Millet, and 910 kg/ha for Proso Millet under S_3 - Mulching. This result confirmerd with work of Mohammadi (2012) (15)(Table 3.).

3.5. Straw yield

The straw yield, representing the amount of above-ground plant material excluding grains, exhibits discernible trends across different millet crops and treatments. Specifically, the straw yields were recorded as 4602 kg/ha for Finger Millet, 3274 kg/ha for Kodo Millet, 2914 kg/ha for Foxtail Millet, 1514 kg/ha for Little Millet, 1497 kg/ha for Barnyard Millet, and 1186 kg/ha for Proso Millet under S_3 - Mulching. These variations underscore the substantial impact of different agricultural practices on the straw yield characteristics of each millet crop, emphasizing the importance of selecting appropriate treatments to optimize overall biomass production and contribute to sustainable farming practices(Table 3.).

3.6. Weed density

The Fig.2. reveals that the data showcases significant disparities in plant densities across different tillage treatments. The No tillage approach yields the highest sedge density at 62.6 No/m^2, suggesting that minimal soil disturbance favors sedge proliferation. The Minimal tillage treatment exhibits a reduced sedge density of 44.1 No/m^2, indicating that even minor soil disruption can hinder sedge growth and broadleaf plant densities respectively. Regarding grass densities are highest under No tillage condition (55.4 No/m^2), while Minimal tillage and Mulching treatments result in lower densities (22.5 No/m^2 and 10.5 No/m^2, respectively), indicating that tillage practices may suppress grass populations.The result confirmed by the Locke *et al.,* 2002 (14) and Swanton *et al*., 2008 (20).

3.7. Rain water use efficiency

Rainwater Use Efficiency (RWUE), a crucial metric reflecting the effectiveness of utilizing rainwater for crop production, showcases distinct trends across different millet crops and treatments. In a thorough comparison of all three treatments, it becomes evident that Treatment S_3 - Mulching consistently results in higher RWUE values compared to No tillage and Minimal tillage. Specifically, RWUE values were recorded as 7.03 kg/ha/mm for Finger Millet, 5.22 kg/ha/mm for Kodo Millet, 6.81 kg/ha/mm for Foxtail Millet, 2.37 kg/ha/mm for Little Millet, 2.35 kg/ha/mm for Barnyard Millet, and 2.13 kg/ha/mm for Proso Millet under S_3- Mulching. These variations emphasize the considerable influence of diverse agricultural practices on rainwater utilization efficiency for each millet crop. The tillage practices influencesconserving water and improving crop productivity confirmed by Jat *et al*., 2009(10) (Table 3.).

4. SUMMARY

Small millet crops, known for their inherent drought tolerance, exhibit superior performance in challenging climatic conditions. A recent study unveiled the benefits of adopting conservation agriculture practices for these crops. This approach not only results in a reduced cost of cultivation but also eliminates the need for tillage, mitigating issues such as poor establishment and high weed population. The study found that a single ploughing significantly lowers weed population, while the adoption of mulching proves instrumental in limiting both weed growth and water loss. As a result, grain yield, and straw yield, with positive yield increases over the control (ranging from 24.3% to 36.1%). The relative water use efficiency (RWUE) also improves from 5.16 to 7.03 kg/ha/mm. Kodomillet shows similar trends with notable increases in grain size, yield, and straw yield, resulting in positive yield increases (10.2% to 28.0%) and improved RWUE (4.08 to 5.22 kg/ha/mm). Foxtail millet demonstrates significant increases in grain yield (1223 to 2914 kg/ha) and straw yield (2000 to 2914 kg/ha), with positive yield increases (54.9% to 63.7%) and enhanced RWUE (4.67 to 6.81 kg/ha/mm). Conservtaion agriculture practices reduced weed growth and helps to avoid the usage of herbicides.

CONCLUSION

From the above summary of results, the following conclusions are drawn:

- Adoption of conservation agriculture results in a reduced cost of cultivation and eliminates the need for tillage, mitigating issues such as poor establishment and high weed population.
- Conservation practices, particularly mulching, prove instrumental in limiting both weed growth and water loss, leading to grain and straw yield increases ranging from 24.3% to 36.1% for small millet crops.
- The relative water use efficiency (RWUE) also improves significantly, from 5.16 to 7.03 kg/ha/mm and help to avoid the usage of herbicides.

- Mulching revolutionizes rainfed small millet farming by conserving moisture, curbing weeds, and boosting yields sustainably. It's the secret weapon for resilient and thriving crops in challenging rainfed landscapes.

REFERENCES

1. Abrol, I.P.; Gupta, R.K.; Malik, R.K. *Conservation Agriculture. Status and Prospects*; Centre for Advancement of Sustainable Agriculture: New Delhi, India, 2005; p. 242.
2. Blessing Mhlanga, Laura Ercoli, Elisa Pellegrino, Andrea Onofriand Christian Thierfelder .2021. The crucial role of mulch to enhance the stability and resilience of cropping systems in southern Africa. Agronomy for Sustainable Development. 41: 29
3. Cameron M. Pittelkow, Xinqiang Liang, Bruce A. Linquist, Kees Jan van Groenigen, Juhwan Lee, Mark E. Lundy, Natasja van Gestel, Johan Six, Rodney T. Venterea & Chris van Kessel. 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature, 517(7534), 365-368.
4. Dalal, R.C.; Allen, D.E.; Wang, W.J.; Reeves, S.; Gibson, I. 2011. Organic carbon and total nitrogen stocks in a Vertisol following 40 years of no-tillage, crop residue retention and nitrogen fertilisation. *Soil Tillage Res.*, *112*, 133–139.
5. Derpsch, R., *et al*. 2014. Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural & Biological Engineering, 7(1), 1-25.
6. Duan, T.; Shen, Y.; Facelli, E.; Smith, S.E.; Nan, Z.2010. New agricultural practices in the Loess Plateau of China do not reduce colonisation by arbuscular mycorrhizal or root invading fungi and do not carry a yield penalty. *Plant Soil*. *331*, 265–275.
7. FAO, 2022. Conservation Agriculture
8. Hobbs, P. R., &Govaerts, B. 2010. Conservation agriculture: what is it and why is it important for future sustainable food production? Journal of Agricultural Science, 148(6), 477-486.
9. Hobbs, P.R.; Sayre, K.; Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. *Philos. Trans. R. Soc. Lond. B Biol. Sci.*, *363*, 543–555
10. Jat ML, Gathala MK, Ladha JK, Saharawat YS, Jat AS, Kumar V, Sharma SK, Kumar V, Gupta Raj. 2009. Evaluation of Precision Land Leveling and Double Zero-Till Systems in Rice–Wheat Rotation: Water use, Productivity, Profitability and Soil Physical Properties. Soil and Tillage Research 105: 112-121
11. Kaschuk, G.; Alberton, O.; Hungria, M. 2010. Three decades of soil microbial biomass studies in Brazilian ecosystems: Lessons learned about soil quality and indications for improving sustainability. *Soil Biol. Biochem. 42*, 1–13.
12. Kassam, A.; Friedrich, T.; Derpsch, R.2019. Global spread of conservation agriculture. *Int. J. Environ. Stud. 76*, 29–51.

13. Kirkegaard, J.A.1995. A review of trends in wheat yield responses to conservation cropping in Australia. *Aust. J. Exp. Agric.*, *35*, 835–848.

14. Locke, M.A.; Reddy, K.N.; Zablotowicz, R.M. 2002.Weed management in conservation crop production systems. *Weed Biol. Manag.*, *2*, 123–132.

15. Mohammadi, G.2012. Living mulch as a tool to control weeds in agroecosystems: A Review. *Weed Control*, *29*, 75–100.

16. Nhamo Nhamo and Olipa N. Lungu. 2017. Opportunities for Smallholder Farmers to Benefit From Conservation Agricultural. https://doi.org/10.1016/B978-0-12-810521-4.00007-4

17. Page KL, Dang YP and Dalal RC (2020) The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. Front. Sustain. Food Syst. 4:31. doi: 10.3389/fsufs.2020.0003.

18. Silburn, D.M. Pesticide Retention, Degradation, and Transport Off-Farm. In No-Till Farming Systems for Sustainable Agriculture; Dang, Y.P., Dalal, R.C., Menzies, N.W., Eds.; Springer: Cham, Switzerland, 2020; pp. 281–297.

19. Somasundaram Jayaraman, Yash P. Dang, Anandkumar Naorem,Kathryn L. And Ram C. Dalal. 2021. Conservation Agriculture as a System to Enhance Ecosystem Services. *Agriculture*, *11*(8), 718.

20. Swanton, C.J.; Mahoney, K.; Chandler, K.; Gulden, R.H. 2008.Integrated weed management: Knowledge-based weed management systems. *Weed Sci*, *56*, 168–172.

Table 2. Effect of Conesrvation agriculture on growth parameters of small millet

Crops	Plant height (cm)			No. of tillers (Nos.)			1000 grain weight		
	S_1 -No tillage	S_2 - Minimal tillage	S_3 - Mulching	S_1 -No tillage	S_2 - Minimal tillage	S_3 - Mulching	S_1 -No tillage	S_2 -Minimal tillage	S_3 - Mulching
C_1 - Finger millet	78.3	89.8	95.7	2	3	4	2.70	2.80	2.90
C_2 - Kodomillet	51.7	68.2	77.1	5	9	12	2.80	3.20	3.90
C_3 - Foxtail millet	80.0	88.1	94.3	2	3	4	2.98	3.05	3.19
C_4 - Little millet	68.3	81.2	93.4	2	4	4	3.44	3.65	3.69
C_5 - Barnyard millet	81.2	92.6	114.1	2	3	4	3.67	3.90	3.98
C_6 - Proso millet	78.3	97.8	114.2	2	3	5	4.75	5.01	5.08

	SEd	**CD (p=0.05)**	**CV (%)**	**SEd**	**CD (p=0.05)**	**CV (%)**	**SEd**	**CD (p=0.05)**	**CV (%)**
S	1.65	4.57	5.79	0.15	0.42	10.53	0.06	0.17	5.41
C	2.69	5.49	6.67	0.16	0.32	7.82	0.11	0.23	6.65
S at C	4.56	NS	-	0.29	0.65	-	0.19	0.40	
C at S	4.66	9.52	-	0.27	0.56	-	0.19	0.39	

Table 3. Effect of Conesrvation agriculture on yield parameters of small millet

Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)			Yield increase over control (%)			RWUE (kg/ha /mm)		
	S_1 - No tillage	S_2 - Minimal tillage	S_3 - Mulching	S_1 - No tillage	S_2 - Minimal tillage	S_3 - Mulching	S_1 -No tillage	S_2 - Minimal tillage	S_3 - Mulching	S_1 - No tillage	S_2 - Minimal tillage	S_3 - Mulching
C_1 - Finger millet	2210	2746	3010	3222	4098	4602	-	24.3	36.1	5.16	6.41	7.03
C_2 - Kodomillet	1745	1923	2234	2413	2730	3274	-	10.2	28.0	4.08	4.49	5.22
C_3 - Foxtail millet	1223	1895	2003	2000	2888	2914	-	54.9	63.7	4.67	6.75	6.81
C_4 - Little millet	570	814	1015	950	1278	1514	-	42.8	78.2	1.33	1.90	2.37
C_5 - Barnyard millet	648	812	1004	965	1226	1497	-	25.3	54.9	1.51	1.90	2.35
C_6 - Proso millet	611	724	910	887	1044	1186	-	18.5	48.9	1.43	1.69	2.13

	SEd	**CD (p=0.05)**	**CV (%)**	**SEd**	**CD (p=0.05)**	**CV (%)**
S	35.11	97.47	7.27	52.73	146.40	7.33
C	54.91	112.14	8.04	81.17	165.77	8.02
S at C	93.65	200.92		138.75	298.00	
C at S	95.10	194.23		140.59	287.12	

Fig.1. Rainfall received during the cropping period

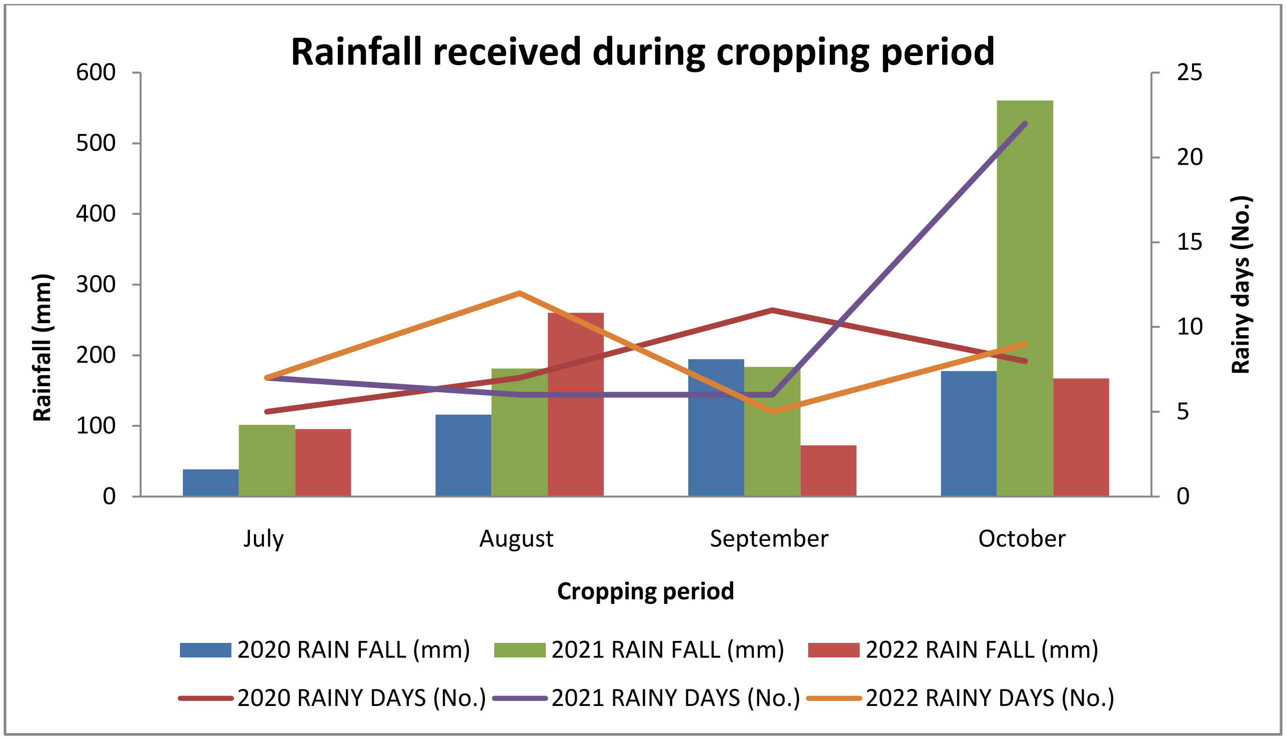

Fig. 2. The effect of conservation practices on total weed dry weight (g m^{-2}) at harvest of small millets